Periodicity of Solar Neutrino Signals at the Sudbury Neutrino Observatory

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There have been reports of observing a 7% modulation of the ^{8}B solar neutrino flux at a frequency of 9.43 y^{-1} based on the measured $\nu - e$ elastic scattering rate in the Super-Kamiokande detector [1–3]. Analyses performed by the Super-Kamiokande collaboration itself did not reveal such periodicity. The periodicity of neutrino signal observed by the Sudbury Neutrino Observatory (SNO) has been analyzed by two methods: Data Compensated Discrete Fourier Transform (DCDFT) method [5–8] and the unbinned maximum likelihood method.

In DCDFT, the trial functions are chosen as $\phi_1(t) = \sin(\omega t)$ and $\phi_2(t) = \cos(\omega t)$. The "power" is defined as

$$P_{DCDFT} \;=\; \frac{NV}{r\sigma^2} \qquad (1)$$

where N is the number of bins, V (=Σz_i^2 with z_i being the projection of the data onto the i$^{\text{th}}$ component of the trial function, or $z_i = \langle \vec{x} | \phi_i \rangle$), σ^2 is the ensemble variance (= $N/(\Sigma 1/\sigma_j^2)$ with the variance of each bin being σ_j^2), and r is the number of degrees of freedom. In this formulation, the i$^{\text{th}}$ data point is defined as the number of events in the bin divided by the livetime of that bin. P_{DCDFT} follows a χ^2 distribution of r degrees of freedom.

In the unbinned maximum likelihood method, the intensity function $\lambda(t|A,B,\delta)$ is defined as $A + B\sin(\omega t + \delta)$, and the log likelihood function is defined as [9]

$$\log L(A,B,\delta) \;=\; \Sigma_{i=1}^{n} \log \lambda(t_i|A,B,\delta) - \int_t \lambda(t|A,B,\delta) \qquad (2)$$

where the summation is over all the events, and the integral is over detector livetime. At each angular frequency ω, the power is defined as

$$P_{ML} \;=\; 2\left[\log L(A,B,\delta) - \log L(B=0)\right] \qquad (3)$$

which follows a χ^2 distribution with 2 degrees of freedom.

Data from the D_2O phase of the SNO experiment were analyzed with the two methods described above. Both P_{DCDFT} and P_{ML} were calculated in the frequency range of 0.001 to 1 day^{-1}. Monte Carlo data sets that simulate the SNO event time distribution were generated to calculate for the significance (or the probability that a data set gives a maximum power larger than a specified value). Figure 1 shows the distribution of maximum power for these Monte Carlo data sets using the DCDFT method. The maximum power at the 10%, 1% and 0.1% significance levels are 9.17, 11.6, 14.1 respectively. Similar distributions are obtained for the unbinned maximum likelihood method.

Sensitivity tests were performed by simulating Monte Carlo data sets of various amplitude ratio B/A and frequencies. Figure 2 shows the power spectrum P_{ML} for a simulated data set with an amplitude ratio of 20% amplitude ratio and a 5-day periodic signal. It is clear that under such scenario, the maximum likelihood method could identify the periodic signal. The DCDFT method has similar sensitivity. We are in the final stage of completing this periodicity analysis, and the results will be reported in the near future.

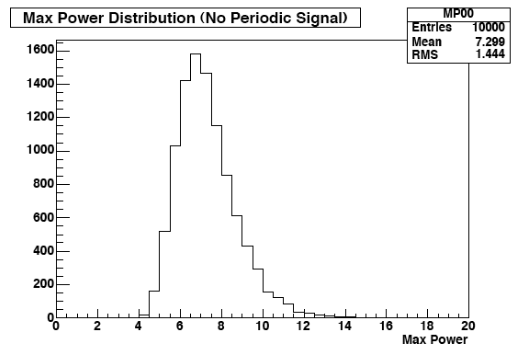

FIG. 1: Distribution of maximum power (P_{DCDFT}) for the 10 000 Monte Carlo data sets.

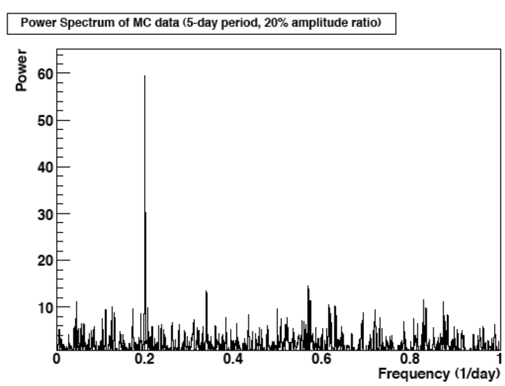

FIG. 2: Power spectrum (P_{ML}) for a simulated data set with a 20% amplitude ratio and a 5-day period.

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